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The P-Star Approach to the Link Between Money and Prices

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THE P-STAR APPROACH TO THE LINK BETWEEN MONEY AND PRICES

ABSTRACT

This paper examines several specification errors in the M2-based P* model and develops an M1-based estimate of this model. The apparent statistical significance of M2 is shown to arise from a spurious regression that uses a nonstationary regressor and because the significance test for M2 is biased by including the influence of a lagged dependent variable whose coefficient is not normally distributed. When these problems are addressed, M2 is not statistically significantly related to the price level. The M1-based P* model exhibits a significant relationship between M1 and the price level, however.

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One of the best know and, now, most suspect economic relationships is that between money and prices. Benjamin Friedman (1988) argues, "the quantitative relationships connecting income and price movements to the growth of the familiar monetary aggregates...utterly fell apart" during the 1980s (mid-1982 to mid-1987). As a result, he claims, "the presumption that 'inflation is always and everywhere a monetary phenomenon' became progressively less compelling as a substantive rather than tautological description." Others, even some who still regard inflation as a monetary phenomenon, have concluded that the M1 money stock measure is no longer closely, or even systematically, related to prices due to financial innovations or other factors. Those who blame financial innovations for this breakdown point out that the line between M2 and prices would not have been affected; consequently they have begun to emphasize the M2-price link.

This paper examines one specific approach, called the P-star approach, to the link between M2 and prices recently developed by Hallman, Porter and Small (1989, 1990). The analysis describes their (HPS) approach as well as several shortcomings in it. The latter include inappropriate constraints on the determinants of inflation and questionable assumptions about the time series properties of the price level, about the stationarity of M2 velocity and about the regressors in their model. When these issues are addressed, the results suggest that there is no statistically significant relationship between M2 and prices. This paper also develops and examines an M1-based variant of the P-star approach. In contrast to the results obtained from the M2-based P-star model, there is a significant relationship between M1 and prices.

I. THE P-STAR MODEL OF INFLATION

In the standard reduced-form approach to the estimation of the relationship of prices to monetary aggregates, inflation depends on long distributed lags of past growth rates of money and on other factors, like supply shocks or price controls.[2/] In contrast, the HPS model relies on the link between the level of the money stock in the previous quarter and the equilibrium price level associated with it, P-star, to determine inflation.

The P-star model is based on two fundamental concepts: (1) a long-run view of the equation of exchange, and (2) the lagged adjustment of prices to their long-run or equilibrium level. The equation of exchange indicates that the level of prices, P, equals the product of money (M) per unit of real output (y), or (M/y), and the velocity of money (V). In the long run, output is presumed to be equal to the economy's potential output, y*. Furthermore, over long periods, velocity is presumed to be well-described by its mean and its trend, if any; in particular, V is independent of the money stock, M, and potential real GNP, y^*. The HPS model uses M2 as the money stock measure. Its velocity, HPS argue, is trendless; consequently long-run velocity, V^*, is simply the mean of M2's velocity, $\overline{V2}$. Thus, in the HPS model, the long-run price level, P^*, equals $(M2/y^*)\overline{V2}$.

The actual price level is assumed to adjust toward the long-run level, P^*, at a constant rate of adjustment, α. In addition, inflation depends on its own past values in the HPS model. Because the sum of past inflation effects is equal to one, however, the dependent variable in the HPS model can be written as the <u>acceleration</u> of the inflation rate, $\Delta\dot{P}_t$. The dynamics of inflation are described by:

$$(1) \quad \Delta\dot{P}_t = \beta_0 - \alpha(\ln P_{t-1} - \ln P^*_{t-1}) + \sum_{i=1}^{n} \beta_i \Delta\dot{P}_{t-i} + N_t + \epsilon_t,$$

where the inflation rate, $\dot{P}_t$, is the annualized continuous rate of increase of the GNP deflator $(400\Delta\ln P_t)$, and α is positive. If the equilibrium price level exceeds the actual price level, the inflation rate temporarily accelerates to close this "price gap;" conversely, if the actual price level exceeds P-star, inflation slows. In the HPS model, four past inflation acceleration terms capture the influence of past inflation on the current inflation (that is, $n=4$). Finally, N_t represents a vector of nonmonetary shocks that includes price control-decontrol influences and energy price effects; HPS use dummy variables to include these effects.[3/]

The analysis that follows uses different measures of nonmonetary variables than those used by HPS in their analysis. The price control variable used here, D, includes both the price control effects that began in the third quarter of 1971 and persisted through the first quarter of 1973, and the decontrol effects that began in the first quarter of 1973 and lasted until the first quarter of 1975; these effects are constrained to sum to zero.[4/] The effect of energy price changes are estimated directly by using the relative price of energy, p^e, which is the ratio of the quarterly average of the producer prices for fuel, related product and power, deflated by the implicit price index for business sector output. Current and lagged values of the annualized continuous growth rate of the relative price of energy, $\dot{p}^e_t$, $[400\,\Delta\ln(p^e_t)]$ are used to capture the effect of energy price changes on the price level.

An estimate of the HPS P-star model which includes these specific nonmonetary variables for the period I/1955 to IV/1988 is:

$$
\begin{aligned}
(2)\quad \Delta\dot{P}_t = \; & \underset{(0.34)}{0.077} - \underset{(-5.22)}{17.220}G2_{t-1} \; \underset{(-9.13)}{-0.747}\Delta\dot{P}_{t-1} \\
& \underset{(-5.60)}{-0.533}\Delta\dot{P}_{t-2} \; \underset{(-4.11)}{-0.381}\Delta\dot{P}_{t-3} \; \underset{(-1.96)}{-0.145}\Delta\dot{P}_{t-4} \\
& \underset{(-2.38)}{-1.166}D_t + \underset{(2.46)}{0.022}\dot{p}^e_{t-2}
\end{aligned}
$$

$\bar{R}^2 = 0.40 \qquad \text{S.E.} = 1.512 \qquad \text{D.W.} = 1.95$

$G2_t$ is the price gap $(\ln P_t - \ln P^*_t)$ that enters with a one-quarter lag on the right-hand side of equation 1, constructed using M2; t-statistics are reported in parentheses. These results are nearly the same as those reported by HPS for a slightly shorter period (I/1955 to I/1988), except for the use of the different measures of the two nonmonetary influences.[5/] The price control variable and the second lag on the change in the relative price of energy are both statistically significant, and their use results in a better fit than when they are replaced by the HPS oil price and price control dummy variables. In this sense, equation 2 is the best representation of the HPS P-star model based on M2 and the point of departure for the problems discussed below.[6/]

II. STATISTICAL PROBLEMS IN THE HPS MODEL

There are five statistical issues that warrant investigation. Two of these involve implicit constraints in the specification of equation 2. A third concerns the assumed behavior of the velocity of M2. A fourth issue concerns the time series representation of the dynamics of inflation, while the final issue concerns the stationarity of the right-hand-side variables used in the HPS model.

A. Implicit Constraints in the HPS Model

The HPS model can be viewed as a constrained version of:

$$(3) \quad \dot{P}_t = \delta_0+\alpha_1 \ln P^*_{t-1}-\alpha_2 \ln P_{t-1}+\delta_1\dot{P}_{t-1}+\delta_2\dot{P}_{t-2} +\delta_3\dot{P}_{t-3}+\delta_4\dot{P}_{t-4}+\delta_5\dot{P}_{t-5}+N_t+\epsilon_t.$$

Five lagged values of past inflation are considered to be significant in the HPS estimate; also, two constraints are employed. The first is that ($\alpha_2=\alpha_1=\alpha$); the second is that the sum of the five δ coefficients, called γ, equals one. When the definition of γ is substituted for δ_1 in equation 3, the result is

$$(4) \quad \Delta\dot{P}_t = \delta_0+\alpha_1 \ln P^*_{t-1}-\alpha_2 \ln P_{t-1}+(\gamma-1)\dot{P}_{t-1}-(\delta_2+\delta_3+\delta_4+\delta_5)\ \Delta\dot{P}_{t-1} -(\delta_3+\delta_4+\delta_5)\Delta\dot{P}_{t-2}-(\delta_4+\delta_5)\Delta\dot{P}_{t-3}-\delta_5\Delta\dot{P}_{t-4}+N_t+\epsilon_t.$$

Equation 4 involves the lagged level of inflation ($\dot{P}_{t-1}$), the lagged level of prices (P_{t-1}) and four lags of the dependent variable ($\Delta\dot{P}$).

Assumptions about the coefficients on ln P_{t-1} and $\dot{P}_{t-1}$ concern stationarity or the absence of unit roots. In the HPS specification (for example, equation 2 above), the price level is assumed to be stationary, given P-star, so that the price level tends to equal P-star (α_2=α_1>0) in the long run. The price level does not have a unit root, given P-star. Inflation, however, is assumed to have a unit root (γ=1), which means that it is not stationary or mean reverting. The latter assumption also means that the sum of the five δ coefficients in equation 3 equals one.[7/] The constraint that γ equals one is not imposed below, but this, in principle, should not effect the significance of M2 per unit of potential GNP. When only statistically significant past inflation effects are included in testing the constraint, it is rejected. The constraint that α_1=α_2=α initially is imposed below, but it is relaxed later in order to focus on the implicit significance of α_1.

B. Equilibrium Velocity in the HPS Model

A third statistical issue in estimating and testing the P-star model concerns the simple characterization of $V2^*$, the equilibrium level of M2 velocity. HPS consider its equilibrium level to be constant and estimated by its sample mean; they also consider the possibility that V2 fell in the 1980s because of financial deregulation, but they reject it.

HPS claim that V2 is stationary, or mean-reverting, so that it fluctuates randomly about a fixed mean.[8/] Schwert (1987) argues that, if the first-difference of a time series is generated by a first-order moving average process, the appropriate test equation for the Dickey-Fuller unit root test is the Dickey-Said specification, which contains 12 lags of the dependent variable--$\Delta \ln V2$ in this case--a constant and the lagged level of the variable being tested ($\ln V2$).[9/] In both the HPS sample period and the period used here, the MA1 parameter for $\Delta \ln V2$ is 0.255 (t=-3.02) and the $\chi^2(10) = 13.39$, indicating that the residuals from this time series process are white noise. Schwert's tabulated critical value (5 percent significance level) for the t-statistic on the lagged level of $\ln V2$ in the relevant test equation with 12 lags, when the MA1 coefficient is 0.255, is between 2.82 and 2.85. The test equation for the period II/1955 to I/1988 is:

$$(5) \quad \Delta \ln V2_t = \underset{(2.00)}{0.0439} - \underset{(-2.03)}{0.0082} \ln V2_{t-1} + \sum_{i=1}^{12} \beta_{t-i} \Delta \ln V2_{t-i}$$

$$\bar{R}^2 = 0.13 \qquad S.E. = 0.0109 \qquad D.W. = 2.00$$

The t-statistic on $\ln V2_{t-1}$ is too small in absolute value (compared with its critical value) to reject the unit root hypothesis.[10/] Thus, according to this specification of the test, $\ln V2$ is not stationary.[11/]

Tatom (1990a) argues that financial innovations affected the velocity of M2. According to this article, M2 velocity had a positive trend from the early 1960s until 1981; adjusted for a significant financial innovation effect, the prior positive trend in M2 velocity and its subsequent decline are quite apparent. A shift in M2 velocity is also suggested by evidence that the trend in M1 velocity shifted in the early 1980s. Such a rise in the demand for M1, or fall in GNP per unit of M1, would reduce the velocity of broader aggregates in the absence of offsetting changes in the demand for non-M1 assets. As Tatom (1988) argues, the M1 velocity trend rate of growth, which is implicit in the constant of M1-based reduced-form GNP growth equations, shifted in the second quarter of 1981. Rasche (1987) dates the shift in the trend of M1 velocity in I/1982, but the earlier shift results in a better statistical fit for models that regress lnV1 on two time trends or ΔlnV1 on a constant and a single intercept shift.

When the growth of M2 velocity (ΔlnV2) from I/1955 to IV/1988 is regressed on a constant and one intercept shift that is allowed to occur in any quarter from I/1980 to I/1984 (with significant first-order autocorrelation correction, as well), the single shift that best fits the data occurs in II/1981. The resulting decline in M2 velocity growth from a 0.4 percent rate to a -1.4 percent rate is not statistically significant (t=-1.47), however, though it does suggest that this would be a likely candidate for dating the shift in a more detailed model of M2 velocity.

If equilibrium velocity has a trend that has shifted, then a formulation like

$$(6)\quad \ln V2_t = \nu_0 + \nu_1 t + \nu_2 t2,$$

where the t time trend equals 1 in I/1955 and rises by one each quarter until IV/1988 and the t2 time trend is zero until II/1981 when it increases by one each quarter until IV/1981, can be used to specify $\ln V2^*$ in the P-star model. Substituting equation 6 into equation 1 results in

$$(7)\quad \Delta\dot{P}_t = (\beta_0 - \alpha\ln\bar{V}\bar{2} + \alpha\nu_0) - \alpha(\ln P_{t-1} - \ln P^*_{t-1}) + \alpha\nu_1 t_{t-1}$$

$$+\alpha\nu_2 t2_{t-1} + \sum_{i=1}^{m} \beta_{t-i}\Delta\dot{P}_{t-i} + N_t + \epsilon_t,$$

where P^* is defined just as it is in HPS ($M2 \cdot \overline{V2}/y^*$). The same substitution can be made in equations 3 and 4, which similarly adds terms like $\alpha_1\nu_1 t_{t-1}$ and $\alpha_1\nu_2 t2_{t-1}$ to the right-hand side and alters the intercept.

When the HPS constraint (γ=1) on the sum past inflation effects in equation 2 is relaxed, and significant M2 velocity time trends are included in an estimate of equation 3, the fifth lag of inflation is not statistically significant.[12] The effect of $\Delta\dot{P}_{t-4}$ on $\Delta\dot{P}_t$ is not significant in the various estimates reported in HPS (1989) either. Thus, δ_5 in equations 3, 4 and 7 is zero. This unconstrained estimate of equation 7 is:

$$(8)\quad \dot{P}_t = \underset{(2.14)}{0.653} + \underset{(2.58)}{0.210}\,\dot{P}_{t-1} + \underset{(2.16)}{0.178}\,\dot{P}_{t-2} + \underset{(1.23)}{0.103}\,\dot{P}_{t-3}$$

$$+ \underset{(2.31)}{0.184}\,\dot{P}_{t-4} - \underset{(-4.13)}{13.515}\,G2_{t-1} - \underset{(-2.60)}{1.255}\,D_t$$

$$+ \underset{(2.17)}{0.016}\,t_{t-1} - \underset{(-2.02)}{0.072}\,t2_{t-1} + \underset{(3.96)}{0.031}\,\dot{p}^e_{t-2}$$

$R^2 = 0.73$ S.E. = 1.479 D.W. = 1.99

The sum of the past inflation effects is 0.675 and the t-statistic for testing whether it is significantly different from one is -6.87, which is significantly below the critical value of -3.45 (5 percent significance) for the Dickey-Fuller test on this sum.[13] Thus, the constraint is rejected. The t-statistics for the trend terms are both significant at a 5 percent level in the unconstrained estimate of equation 2. Since the G2 coefficient is -13.515, the implied annual continuous rate of growth of V2 is 0.5 percent until I/1981, and -2.1 percent subsequently. Thus, equation 8 also suggests that the assumption that the logarithm V2 is mean-reverting is incorrect; its (non-zero) trend shifted in the early 1980s.[14]

C. Dynamic Anomalies in the HPS P-star Model

Ignoring the nonmonetary influences, the HPS model embeds the M2-based price gap, G2, in a pure time series equation--a fourth-order autoregressive (AR4) model for differences in inflation. This AR4 time series model has a standard error of estimate equal to 1.695 and an adjusted R^2 of 0.25 for the same period. Thus, much of the explanatory power in the HPS model arises from its time series components. A first-order moving average (MA1) model for changes in inflation, however, is a superior time series model of inflation, at least for the GNP deflator.[15] The MA1 parameter is 0.601 (S.E.=0.069); it is significantly different from zero (t=8.68) and from one (t=-5.76). This model has a standard error of estimate of 1.670 for the same period, slightly lower than that for the AR4 model, and it uses fewer degrees of freedom than the AR4 model; the adjusted R^2 for this model is 0.27. The Schwartz Bayesian criterion (SBC) statistic, which is used to find the optimal lag length of AR processes, is minimized with three lags (AR3), where the statistic is 544.35. The superiority of the MA1 specification also is indicated by its lower (533.48) SBC value.

The choice of the AR4 specification gives rise to peculiar dynamics in the adjustment of inflation to a permanent change in money growth. An increase in the money growth rate causes inflation to rise far above or overshoot its higher equilibrium pace and to cycle both upward and downward for a considerable period before it settles down to this new equilibrium.

The figure demonstrates this characteristic of the HPS P-star adjustment process. While the time path of adjustment in the figure is based on equation 2, the general pattern does not depend on this choice. In the figure, a 4 percentage-point rise in M2 growth raises the rate of increase of P-star, the equilibrium inflation rate, by 4 percentage points. The actual inflation oscillates widely, however, initially rising more than 3 percentage points above and then falling 2.5 percentage points below the indicated new equilibrium value; it then cycles dramatically for decades. Inflation surges to an initial peak of more than 7 percent in about six years, then declines to about 1.5 percent in 12.5 years, before rising again.

Equilibrium inflation (the rate of increase in P-star) increases point for point with money growth, but the adjustment to this pace takes a relatively long time to stabilize. Indeed, in the figure, inflation still exhibits a peak-to-trough variation of inflation of 3.1 percent to 4.7 percent after nearly 40 years of adjustment! More importantly, however, the P-star model postulates a dynamic adjustment process that has little foundation in the theoretical literature and virtually no precedent in earlier estimates of money growth's effect on inflation.[16/] These features of the HPS model arise from the use of the AR4 specification for changes in inflation along with the level of the lagged price gap.[17]

D. Stationarity and the HPS Model

The fifth and final statistical problem is the stationarity of the variables used in the regressions. HPS (1989) point out that inflation is not stationary, and they suggest that the stationarity of the price gap measure, G2, is sample specific. Granger and Newbold (1974) have shown that including a nonstationary regressor in an ordinary-least-squares regression can yield t-statistics that indicate "significant" statistical relationships where none actually exist. If the regressors in the test equations are not stationary, then a sufficient degree of differencing of the test equation can eliminate the difficulty.

Equation 4 reports one way to transform equation 3 to secure the desired stationarity of the error process if inflation is not stationary, but its first-difference and the right-hand-side variables are. An alternative way would be to simply difference equation 3. If the gap term (G2), or its two components in equation 3 are also not stationary, then the transformation in equation 4 is not sufficient. In this case, if the first-difference of G2 (and N_t) is stationary, then the structure of equation 3 is appropriately estimated by first-differencing the equation. The first-difference of equation 3, modified for the potential velocity trend shift, is:

$$
\begin{aligned}
(9)\quad \Delta\dot{P}_t = {} & (\alpha_1\nu_1) + \alpha_1\ \Delta\ln P^*_{t-1} - \alpha_2\ \Delta\ln P_{t-1} + \delta_1\Delta\dot{P}_{t-1} \\
& + \delta_2\Delta\dot{P}_{t-2} + \delta_3\Delta\dot{P}_{t-3} + \delta_4\Delta\dot{P}_{t-4} + \delta_5\Delta\dot{P}_{t-5} \\
& + \alpha_1\nu_2\ \Delta t2_{t-1} + \Delta N_t + \epsilon'_t
\end{aligned}
$$

where ϵ'_t is a normally distributed random disturbance term. In this case, the unit root hypothesis for the level of prices (α_2=0) is tested by the coefficient on the growth rate of prices ($\Delta \ln P_{t-1}$) and the second unit root assumption for inflation (γ=1) is absent; in principle, this will not affect the other properties of the model. When the constraint (α_1=α_2=α) is imposed on the right in equation 9, $\Delta G2_{t-1}$ replaces the $\Delta \ln P^*_{t-1}$ and $\Delta \ln P_{t-1}$ terms.[18/]

Unit root tests show that the price gap, G2, is not stationary. When the first- difference of G2 is regressed on a constant, its lagged level and two, eight and 12 lagged values of the dependent variable, the t-statistics for the lagged level of G2 are -2.81, -2.45 and -2.18, for two, eight and 12 lags, respectively.[19/] The critical value of the Dickey-Fuller test statistic is -2.89, however, and the critical statistic value for the test proposed by Schwert (1987) is about -2.82.[20/] These statistics do not reject the presence of a unit root for G2 using either specification for the test.[21/]

Inflation also is not a stationary time series process, as HPS note. When the change in inflation ($\Delta\dot{P}_t$) is regressed on its lagged level ($\dot{P}_{t-1}$), the first four of its own past values and a constant, the t-statistic on the lagged inflation rate is -1.79, which is not statistically significant.[22/] More lags on the dependent variable are unnecessary to show that inflation has a unit root.

Since the gap measure is nonstationary, the estimates in equations 2 and 8 may be spurious. This problem is avoided by estimating equation 9 with (α_1=α_2=α). The first-differences of $\dot{P}_t$, G2, t2, D and $\dot{p}^e$ are stationary. In the resulting estimate, the second to fourth lag of the dependent variable are not statistically significant, nor is $\Delta t2_{t-1}$; these insignificant variables are omitted in the estimate reported in the first column of table 1. The coefficient estimates theoretically are identical to their counterparts in equations 3, 8 and 9 except for the omission of the insignificant variables.

Table 1 also reports an estimate of equation 9 with an MA1 error process, again deleting insignificant variables. No lagged dependent variables are significant when the significant MA1 correction is included; the trend shift ($\Delta t2$) is significant, however.

The most important change in table 1 is that the effect of the price gap term measured using M2 is insignificantly different from zero, using the conventional (two-tail) 5 percent significance criterion. Assessing the statistical significance of the $\Delta G2$ coefficient is not so clear-cut, however, because the coefficient is the constrained estimate of the effect of past inflation (recall that $\Delta \ln P_{t-1}$ equals $\dot{P}_{t-1}$ 1/400) and of the past growth of P-star ($\Delta \ln P^*_{t-1}$) on the current acceleration in inflation ($\Delta \dot{P}_t$). The theoretical probability distributions of these two effects are not the same. The appropriate test statistic for the former effect is a Dickey-Fuller statistic, as adjusted by Perron (1989), which has a critical value (5 percent significance level) of -3.22. The appropriate test statistic for the $\dot{P}^*_{t-1}$ term is a standard t-statistic, which has a critical value (5 percent significance level, two-tail test) of 1.96.

A simple way to separate these two effects and test each influence is to relax the constraint that $\ln P_{t-1}$ and $\ln P^*_{t-1}$ have equal-sized and opposite-signed effects on inflation. When this constraint ($\alpha_2=\alpha_1=\alpha$) is relaxed, the result is:

$$\text{(10)}\ \Delta\dot{P}_t = \underset{(0.75)}{0.076} + \underset{(1.62)}{13.685}\ \Delta\ln(M2_{t-1}\ \overline{V2}/y^*_{t-1})\ \underset{(-1.74)}{-0.0398}\ \dot{P}_{t-1}$$

$$\underset{(-3.43)}{-1.983}\ \Delta D_t\ \underset{(-2.35)}{-0.252}\ \Delta t2_{t-1} + \underset{(2.89)}{0.028}\ \Delta\dot{p}^e_{t-1}\ \underset{(9.10)}{-0.701}\ \epsilon_{t-1}$$

$\overline{R}^2 = 0.38$ S.E. = 1.531 D.W. = 1.95

Neither component of $\Delta G2$ is statistically significant at a 5 percent level. The t-statistic for the coefficient on $\dot{P}_{t-1}$ is well below the absolute value of the relevant Dickey-Fuller statistic (as adjusted by Perron) of -3.22. This test is a unit root test for $\dot{P}_t$, but its coefficient is that for the price gap, so its significance indicates whether the price level is stationary, given P^*, which is the fundamental hypothesis in the P^* model. Similarly, the test statistic (1.62) for whether M2 per unit of potential output affects prices is well below the conventional 5 percent significance value of 1.96. According to both of these estimates, the hypothesis is rejected. The remainder of the coefficients are essentially unchanged by this substitution. Moreover, when $\dot{P}_{t-1}$ is dropped from equation 10, the t-statistic for the M2-based $\Delta\ln P^*_{t-1}$ measure falls to 0.80. Since neither component of $\Delta G2$ is statistically significant, the P-star measure based on M2 is uninformative for inflation.[23/] This insignificance does not arise from the substitution of the MA1 process for the lagged dependent variables or from the inclusion of $\Delta t2_{t-1}$. So long as the two components of $\Delta G2$ are separated, M2 per unit of potential output is statistically insignificant with or without the inclusion of $\Delta t2$ in estimates that either include the lagged dependent variables or include the MA1 term. Thus, the insignificance of M2 per unit of potential output does not arise from these choices.

E. Summary

The HPS P-star model is flawed in several respects. The construction of the equilibrium price level based on M2 relies on a questionable assumption: the stationarity of lnV2. More importantly, the model assumes stationarity of the price gap term which, at least for the periods examined here, fails to hold. The HPS estimates also employ an autoregressive time series specification for accelerations in inflation that is an imperfect substitute for an MA1 error process. Finally, the price gap term in the HPS model constrains P-star to have an effect equal and opposite to the mean reversion coefficient on the price level ($\ln P_{t-1}$); the two components are not significantly different from zero when estimated in first-difference form, however.

These criticisms point up the difficulties in implementing the concept of an equilibrium price level. In addition, the results show that the choice of time series specification is central to the implications for the short-run dynamics of price adjustment. The most damaging result for the HPS P-star model, however, is that the M2-based P-star measure is found to be statistically insignificant in explaining the level of prices when the HPS model is differenced and the constraint implicit in the price gap is relaxed.

III. DOES M1 PER UNIT OF POTENTIAL OUTPUT EXPLAIN THE PRICE LEVEL?

A. An M1-Based P-Star Model

There is no *a priori* reason why the link between money and prices is best represented by a P-star measure based on the M2 monetary aggregate. The HPS P-star approach, for example, also can be used to model the link between M1 and prices. Equation 6 can be used to specify the trend structure of lnV1 since M1 velocity has a positive trend rate of growth from 1955 to 1981 and a slower trend growth rate thereafter.[24/]

To measure the price gap ($\ln P_{t-1} - \ln P^*_{t-1}$) using M1, P-star is measured as the product of (M1/y*) and V1*, where V1* is the equilibrium trend level (the fitted value from the M1 version of equation 6). To implement this model, the price gap term in equation 1, $-\alpha(\ln P_{t-1} - \ln P^*_{t-1})$, is broken into two parts: the first, called G1, equals $-\alpha[\ln P_{t-1} - \ln(M1_{t-1}/y^*_{t-1})]$; the second part is the term $\alpha \ln V1^*_{t-1}$, which equals $\alpha[\nu_0 + \nu_1 t_{t-1} + \nu_2 t2_{t-1}]$.

The comparable estimate to equation 2 for the P-star model using M1 for I/1955 to IV/1988 is:

$$
\begin{array}{llllll}
(11) & \Delta\dot{P}_t = & 17.800 & -\ 0.755\Delta\dot{P}_{t-1} & -\ 0.549\Delta\dot{P}_{t-2} & -0.394\Delta\dot{P}_{t-3} \\
 & & (4.54) & (-8.89) & (-5.52) & (-4.05) \\
 & & -\ 0.159\Delta\dot{P}_{t-4} & -\ 15.859G1_{t-1} & +\ 0.123(t_{t-1}) & \\
 & & (-2.05) & (-4.49) & (4.29) & \\
 & & -\ 0.165(t2_{t-1}) & -1.397D_t & -\ 0.022\Delta\dot{p}^e_{t-1} & \\
 & & (-3.59) & (-2.86) & (-2.17) &
\end{array}
$$

$\bar{R}^2 = 0.37$ S.E. = 1.554 D.W. = 1.87

As the results show, the gap measure based on M1, G1, both velocity trend terms and the constant term are all statistically significant.

The energy price and price control variables are also significant in the M1 variant of the P-star model; however, there is a different pattern of energy price effects in equation 11 compared with equation 2. Two lagged values of the growth of the relative price of energy (t-1 and t-2) are included, with the sum of their coefficients constrained to zero. The F-statistic for this constraint is $F_{1,125}=0.10$, which is not significant. Thus, a rise in energy prices has no permanent influence effect according to equation 11. Initially, inflation falls; it then rises by an equal and offsetting amount.[25/] Only the latter positive effect is statistically significant in the M2-based estimates above.

The expression for the equilibrium velocity of M1 can be derived from equation 11 by dividing the constant and trend term coefficients by the absolute value of the estimated gap (G1) coefficient. The expression for the equilibrium level of ln V1 is (1.1224 + 0.0078t - 0.0104t2). This implies an annual trend, measured at a continuous rate, of 3.11 percent until 1981 and a subsequent trend of -1.04 percent.[26/] A regression of lnV1 on a constant, t and t2 for the same period results in the nearly identical expression: (1.1050+0.0079t-0.0114t2), where the t-statistics are 73.40, 34.38 and -11.11, respectively.[27/] Without the autocorrelation correction, the lnV1 expression is nearly the same (1.1088+0.0080t-0.0115t2) and the t-statistics, of course, are much larger; the Durbin-Watson statistic is 0.19, however.

The residuals from the OLS estimate do not have a unit root, indicating that lnV1 is trend-stationary. When the first-difference of the OLS residuals are regressed on the lagged level of the residual and four lagged dependent variables, the t-statistic on the lagged level of the residual is -3.22. This is also the critical value for such a test, according to Perron (1989).[28]

B. Statistical Tests and Refinements of the M1-Based P-Star Model

Equation 11 potentially is subject to the same reservations as the M2-based estimate discussed above. Specifically, the appropriate lag structure for past inflation effects is open to question, as is the choice of the MA1 correction instead of, or perhaps as well as, the lagged inflation effects, the stationarity of the gap measure, and the determination whether the lagged price level has a significant and opposite-signed effect to that of lagged money per unit of potential output.

Equations 11 suffers from the same lack of stationarity of the gap term, G1, as G2 above. Hence, the estimate may be spurious. In particular, when $\Delta G1_t$ is regressed on a constant, its lagged level, $G1_{t-1}$, and two, eight and 12 lags of $\Delta G1$, the t-statistics for the $G1_{t-1}$ coefficient are -2.25, -2.21 and -2.00, respectively. These are two small in absolute value to reject the unit root hypothesis when compared with the critical augmented Dickey-Fuller statistic of -2.89, or, following Schwert, -2.82. Thus, G1 is not stationary.

The appropriate estimating equation for the M1-based model is equation 9, again with the $(\alpha_1=\alpha_2=\alpha)$ constraint imposed so that $\Delta G1_{t-1}$ replaces the $\Delta \ln P^*_{t-1}$ and $\Delta \ln P_{t-1}$ terms. This estimate, including only those variables that are statistically significant, is shown in the left-hand column of table 2. Just as for the M2-based model, however, the MA1 error process is significant for the M1-based model. This estimate is also reported in table 2. The lagged dependent variables and $\dot{p}^e_{t-1}$, which enter significantly when the MA1 specification is excluded, are not statistically significant when the MA1 term is included; these insignificant terms are not reported in table 2. Unlike the case for the M2-based model with the MA1 error process, the price gap term, $\Delta G1_{t-1}$, remains strongly significant.[29] The MA1 coefficient in the second column of table 2 is relatively large, 0.705 (S.E.=0.110), suggesting that the model has been over-differenced. While the evidence for overdifferencing is stronger here than for the M2-based model, it is not statistically significant and would not bias the significance of the gap coefficient in any event.

Both of the components of the price gap term $\Delta G1_{t-1}$ [$\dot{P}_{t-1}$ and $\Delta \ln(M1_{t-1}/y^*_{t-1})$] are statistically significant, unlike those in the M2-based estimate. The t-statistic for the M1 component, $\Delta \ln (M1_{t-1}/y^*_{t-1})$, is 9.13 and that for the lagged rate of price increase is -7.66; both are substantially larger in absolute value than their respective critical values. Thus, the M1-based model in the second column of table 2 contains a significant link between M1 and prices.

The inflation adjustment path associated with the M1-based model in the second column of table 2 is more similar to earlier reduced-form estimates than is the adjustment path derived from the HPS M2-based model and shown in the figure above. For example, after five years (20 quarters), the inflation adjustment to a permanent rise in money growth in the MA1-adjusted equation in table 2 is three-fourths complete; in a typical reduced-form form equation like that in Tatom (1988), this adjustment is complete after 20 quarters. The adjustment path based on the M1A-adjusted equation, like earlier reduced-form estimates, is continuous and does not overshoot or oscillate; the adjustment process takes about 60 quarters or 15 years to be complete, however. For example, for the same experiment conducted and shown in the figure above, where M1 growth rises 4 percentage points and raises the equilibrium inflation rate from zero to 4 percent, the actual inflation rate rises at a decreasing rate from zero in quarter 7 to 3 percent in quarter 27. After 60 quarters (quarter 67), the inflation rate converges to its equilibrium pace of 4 percent.

IV. CONCLUSIONS

Considerable doubt has arisen in the past decade about the existence of a link between money and prices. More recently, Hallman, Porter and Small have developed a model of inflation that directly links inflation to the growth of M2. The HPS model and its estimation raise econometric issues that are seldom explored in inflation modeling. This article discusses this model in detail and examines some shortcomings of the HPS P-star approach.

The P-star equation for M2 was found to be subject to a spurious regression bias because its principal variable, the price gap, is nonstationary. Moreover, the critical HPS assumption of mean-reverting behavior for V2 is also rejected. The results indicate that there was a significant velocity shift for M2 in the 1980s. The analysis here also suggests the importance of accounting for a significant MA1 error process in modeling the first-difference of the inflation rate. Finally, differencing the underlying model to achieve stationarity and relaxing the constraint that lagged inflation and P-star have equal-sized and opposite signed effects, are shown to result in the insignificance of the HPS P-star measure.

A P-star model otherwise comparable to the HPS model, but constructed using M1, fits the data well; this model suffers from the same spurious regression problem as the M2-based model, however. When this problem and the others noted for the M2-based model are addressed, the M1-based P-star measure remains strongly significant. The dynamics of inflation in the M2-based P-star model also was shown to exhibit implausible oscillations and an extremely long adjustment period. This problem does not arise for the model containing the significant M1-price link found here because the constrained past inflation effects that give rise to such dynamics are rejected and, therefore, omitted.[30/]

The M1-based results suggest that there is a significant and exploitable link between M1 and prices. A significant break in the trend of velocity is found here for both M1 and M2, however. Notwithstanding this shift, there is a statistically significant one-to-one relationship between increases in M1 growth and increases in inflation.

To the extent that the use of M2 targeting in the conduct of monetary policy is premised upon either a constant or mean-reverting velocity of M2, or on a significant link between the M2-based P-star measure and prices, it is flawed. Nevertheless, monetary aggregates and prices are significantly linked through an equilibrium price level, in particular, one based on M1 and its trend velocity. Whether the link between M2 and this P-star measure supports the use of M2 for policy purposes is not examined here.

FOOTNOTES

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1/ See, especially, Cox and Rosenblum (1989) Friedman (1988), Haslag (1990) and Mehra (1988) for recent examples of this argument. The effects of financial innovations on the use, composition and demand for M1 and M2 recently have been examined in Tatom (1990a).

2/ See Stockton and Glassman (1987) or Mehra (1988) for a comparison of reduced-form models to other inflation models. Mehra (1988) presents one of the few examples of a reduced-form inflation equation that uses M2; however, he uses much shorter lags for both M1 and M2 than those estimated for M1 in other reduced-form models. See Tatom (1981) for example.

3/ In the HPS model, both price controls and energy price shocks are handled with dummy variables. The price control variable (PC1PC2, here) is a dummy variable that equals one in III/1971 to IV/1972 and minus one from I/1973 to IV/1974; otherwise this variable equals zero. HPS claim that only the 1973-74 energy price rise has a significant effect on inflation. They control for it by using a dummy variable (called DOS1) that equals one in IV/1973, minus 1 in I/1974 and zero otherwise.

4/ Both nonmonetary variables used below are discussed in more detail in Tatom (1981). The price control-decontrol dummy variable, D_t, used here has a value of one from III/1971 to IV/1972, two-ninths in the first quarter of 1973, minus seven-ninths in each quarter from II/1973 to I/1975, and zero otherwise. This pattern imposes a constant average reduction in the measured inflation rate in III/1971 to I/1973, and a constant average increase in measured rates of inflation in I/1973 to I/1975. The two opposite effects are nearly offsetting in I/1973 (the overlapping quarter). The specific values for the dummy variable were chosen so that the price level would be unaffected by this intervention after I/1975.

5/ HPS omit the intercept term because it is insignificant. HPS use a sample period of I/1955 to I/1988. The estimates reported here use a revised measure of the y^* series used in HPS (1990) and provided to the author by Richard Porter; it also uses a sample period that ends in IV/1988, the latest quarter for which HPS (1989) provide the earlier y^* data. The use of their earlier estimates does not affect the conclusions below in any fundamental ways, however, although the reported results are generally slightly stronger using the older HPS measure.

6/ When the HPS variables, PC1PC2 and DOS1, are used in equation 2 in place of the nonmonetary variables, the standard error of the estimate is higher whether each variable is substituted separately or jointly. When PC1PC2 is added to equation 2, it is not significant (t=-0.33). When DOS1 is added to the equation, it has a significant coefficient of 2.284 (t=2.15), but there is little change in the energy price coefficient, 0.024 (t=2.56), or other coefficients; the price control variable's coefficient of -1.138 (t=-2.33) is nearly the same in this case, too. Although the standard error of the estimate drops to

1.498 when DOS1 is included, this variable is excluded in the estimates below because its effect is orthogonal to the energy price and price control variables and its inclusion is otherwise unmotivated. None of the conclusions below are affected by the substitution of the nonmonetary variables used here. Kuttner (1989, 1990) also questions the nonmonetary measures used by HPS; he uses changes in nominal petroleum prices to capture energy shocks and omits price controls and decontrol variables.

[7] HPS (1989, p. 12) indicate that they test the second assumption (γ=1); they only report one instance where they conduct this test, however, and it is for a more general specification which they also reject. In this test, HPS suggest that the constraint is not rejected. They also do not report whether they examined the hypotheses α_1, α_2=0.

[8] The power of unit root tests and the importance of their implications are the subject of growing doubt. See Christiano and Eichenbaum (1990) and Diebold and Rudebusch (1990). The latter argue that the power of the conventional unit root test is "likely to be quite low." Unlike Schwert (1987), who argues that the conventional test can be biased in favor of stationarity, they argue that the unit root test can be biased against stationarity when a process is fractionally integrated.

[9] When only four lagged values of the dependent variable are used, the t-statistic on $\ln V2_{t-1}$ is -2.94 which is marginally statistically significant and indicates that the series is stationary; this test, however, is biased. See Schwert (1987).

[10] The β coefficients on the lagged growth rates are not reported because they are unimportant for the purpose at hand and require considerable space to present.

[11] Rasche (1989) argues that the stationarity of V2 is doubtful. Tatom (1990) shows that M2 is distorted by an amount proportional to the share of money market deposits in M2. An M2 velocity series that incorporates an adjustment for this bias also has a unit root, however.

[12] Kuttner (1989, 1990) also has criticized the constraint that γ equals one. He argues that it leads to the overshooting and oscillating properties of inflation that are discussed below. Kuttner removes overshooting by altering the model to use the change in the past gap ($\Delta G2_{t-1}$), rather than its level ($G2_{t-1}$), and he adds two past levels of the gap between actual and potential real GNP. These output gaps are not significant when added to equation 2. The second lag of the price gap is statistically significant when added alone to equation 2, however. HPS suggest that this second lag is insignificant; they claim that this insignificance (absent here) provides evidence against the need to difference equations like 2 or 3.

[13] Fuller, Hasza and Goebel (1981) explain that the Dickey-Fuller test for a unit root is the appropriate test for this constraint on lagged dependent variables. The hypothesis tested here concerns the sum of a given set of significant past inflation rate terms; the test requires using the same test statistic as the unit root test. When the trend and its shift are not included in equation 8, the constraint that the summed coefficients on past inflation equal one is not rejected using the Dickey-Fuller test. In this case, the value of the t-statistic for testing whether the sum for the significant four lagged

inflation effects equals one is -2.11, which is smaller in absolute value than the critical value of -2.89. Note that the point of these tests is not to determine whether inflation has a unit root. Such a test would require using more lagged dependent variables according to Schwert (1987).

14/ This argument and the evidence in equation 8 are only suggestive; in particular, it is not intended to show that lnV2 is trend stationary. It is argued below that G2 is not stationary, but ΔG2 is stationary so that estimates based on V2 or G2 may be spurious. These points and their implications are unaffected by whether M2 velocity has a trend or not.

15/ For example, Rasche (1987) and (1989) uses an MA1 model of inflation as its best time series representation. For the period used here, this model has a Box-Pierce Q-statistic for 12 lags of 5.56; thus, the hypothesis that the errors are white noise cannot be rejected at a 5 percent significance level. The errors from the AR4 model are also white noise. The principal difference between the MA1 and AR4 models is that the MA1 model has a slightly superior fit and uses relatively fewer right-hand-side variables and so has a larger number of degrees of freedom. Rasche (1989) points out the near equivalence of an AR4 and MA1 model, where the former has geometrically declining coefficients like those in the HPS model.

16/ Humphrey (1989) points out that some earlier statistical analyses were based on movements in the price level relative to an equilibrium price level; moreover, he argues that "overshooting" is a characteristic of some theoretical models. Thus, there are some precedents to these two aspects of the P-star model. He provides no evidence, however, that such long and oscillating responses of inflation to a change in money growth were anticipated or actually observed in any earlier work. Gordon (1987), pp. 252-63, shows that a relatively mild degree of overshooting can occur for a relatively short time if inflationary expectations are adaptive. Hallman, Porter and Small (1989) dismiss the relevance of the peculiarities shown in the figure for policy purposes. They argue that a steady rate of inflation can be achieved based on the model, after a brief transition in which a nonconstant money growth rate is adopted.

17/ The overshooting and cycling properties arise solely from the assumption that inflation is an autoregressive process with a unit root. This assumption results in the AR4 specification for changes in inflation. Without this assumption, the inflation rate would be the dependent variable in equation 1 and the lagged changes in inflation would not appear on the right-hand side. In this case, inflation would neither overshoot nor cycle when the growth of P-star changes. When only the unit root assumption for the autoregressive process is relaxed below, cycling is eliminated, but overshooting is not.

18/ An alternative approach is to difference equation 4. When this is done, however, the results are the same as below. This approach has one advantage: it directly allows testing the (γ=1) constraint. The constraint is rejected in this case; indeed, γ is not significantly different from zero.

19/ For 12 lags, the regression is estimated over the period III/1955 to IV/1988; otherwise, the sample period is I/1955 to IV/1988.

[20] The MA1 coefficient for the change in G2 is 0.52. This series is not well-described as a MA1 process, however, since the residuals from the MA1 model are not white-noise.

[21] G2 is not stationary during the HPS sample period either. The t-statistics for the lagged G2 measure for the period I/1955 to I/1988 using two, eight and 12 lagged values of $\Delta G2$ are: -2.65, -2.34 and -2.11, respectively, which are also below the unchanged critical values in absolute value. Using the y^* measure HPS (1989) used to construct G2, these t-statistics are lower in magnitude: -2.42, -2.13 and -1.95, respectively. To check further on whether the nonstationarity of G2 is sample-specific, 21 periods of 14-year lengths were selected beginning in I/1955 to IV/1968 and continuing to I/1975 to IV/1988. Unit root tests using four lagged dependent variables found only three periods of possible stationarity: the periods beginning in I/1963, I/1964 and I/1965. When eight lags are used, G2 also has a unit root for these periods.

[22] This unit root result is counter to the rejection of the constraint on the sum of past inflation effects reported above for equation 8, but the latter result holds only for the sum of the included significant effects.

[23] Christiano (1989) argues that the forecasting performance of the HPS P-star model like equation 2 compares quite unfavorably with the performance of several other inflation models.

[24] An M1 version of equation 6 is used to specify the structure for equilibrium $V1^*$ in the M1-based P-star equation. When it is estimated independently, however, it requires a statistically significant second-order autocorrelation correction. This

autoregressive error structure is statistically insignificant when included in the estimation of equation 11 below. Since the inclusion of this error structure has no effects on the other estimates in the equation, it is omitted in the various estimates below that use M1.

25/ The permanent effect of a supply shock on prices arises from a change in y^*, in theory, but the y^* series used here is not significantly negatively correlated with energy prices. The effects of energy price increases on inflation are generally positive in the estimates here. This suggests that the y^* effect is generally biased downward in magnitude so that the effect of an energy price rise (fall) shows up as a permanent rise (fall) in equilibrium velocity. In addition, however, M1 velocity is significantly depressed temporarily by a rise in energy prices, because, initially, output falls more than prices rise; see Tatom (1981). In the P-star framework, this velocity effect can show up as a transitory negative effect of energy prices on the inflation acceleration, as observed here, independent of any bias in the potential output series.

26/ The decline in the inflation rate, given money (M1) growth, found in Tatom (1988) is 4.5 percentage points, not much different from the 4.25 percentage-point decline here. On the other hand, a direct estimate of the decline in the M1 velocity trend growth in the same study shows a fall from a 2.6 percent rate of increase to a 3.3 percent rate of decline, a drop of 5.9 percentage points. An estimate of the M1 velocity trend-rate decline using the approach taken by Rasche (1987) shows a decline of 2.35 percentage points in the drift of M1 velocity for the sample period I/1953 to IV/1985. See Tatom (1990a).

27/ This equation has an adjusted R-squared of 0.998, a standard error of 0.0107 and a Durbin-Watson statistic of 1.90; the estimate includes a correction for second-order autocorrelation where ρ_1=1.114 (t=13.13) and ρ_2=-0.237 (t=-2.79).

28/ When the only significant first-lagged value of the dependent variable is used instead of four lagged dependent variables, the t-statistic is -3.23, which slightly exceeds the critical value.

29/ The implied trend M1 velocity growth for this estimate is a continuous annual rate of 4.1 percent from 1955 to I/1981; it has declined at a -4.5 percent rate since then. These velocity growth rates and the associated decline in velocity are much larger in absolute value than those cited in footnote 26 above.

30/ An earlier version of this paper, Tatom (1990b), finds that velocity trend shifts and stationarity are also problems for M1- and M2-based distributed lag reduced-form models for inflation. First-differencing and correcting for the significant MA1 error process yields exactly the same insignificant results for M2 and significant results for M1 as here, but the M1-reduced form fits the data better than the M1-based P-star model given in the second column of table 2.

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Table 1
First-Differenced Specifications of the M2-Based P-Star Model

<u>Dependent Variable</u>: $\Delta\dot{P}_t$

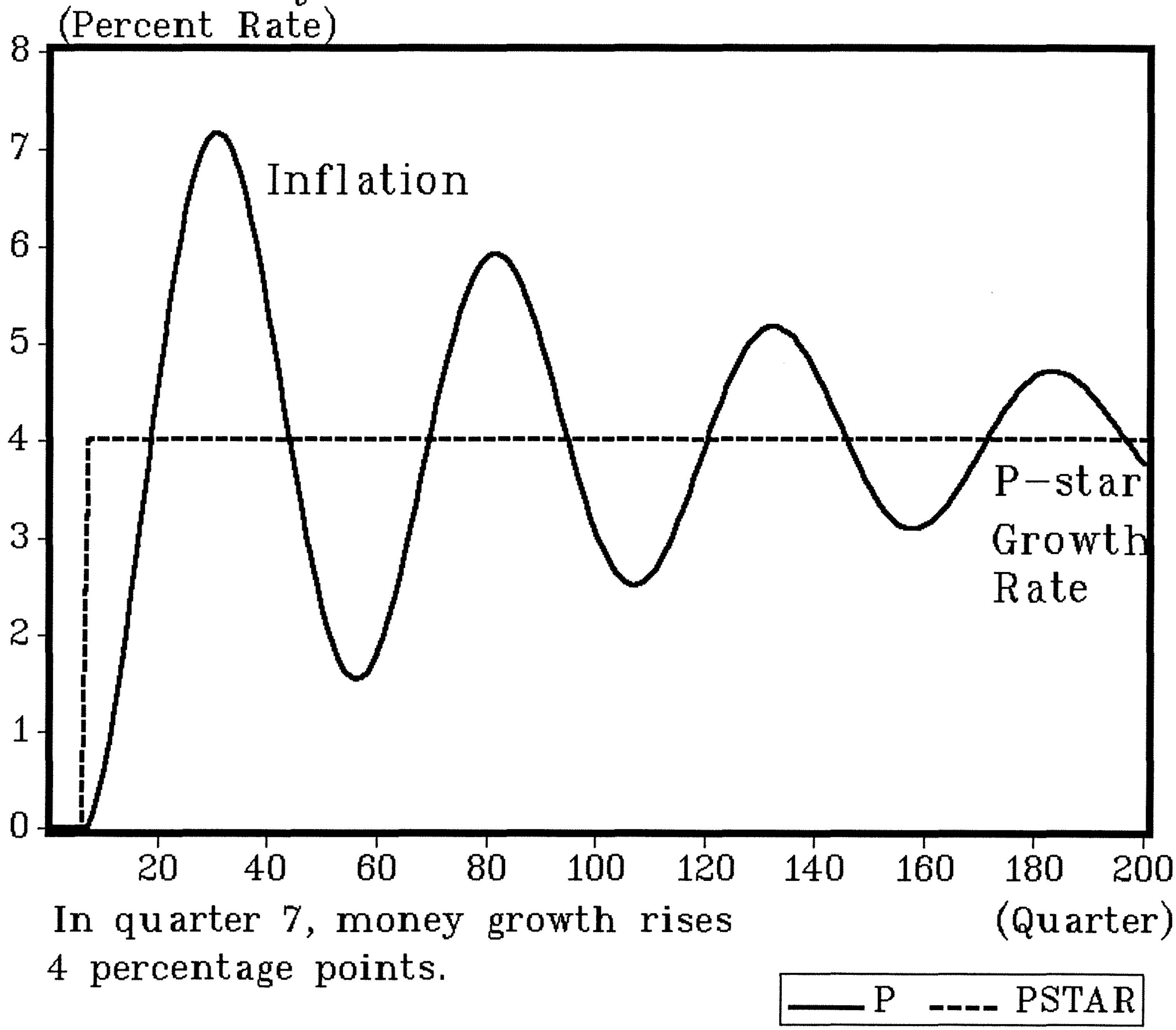
Constant	0.021 (0.15)	0.054 (1.20)
$\Delta G2_{t-1}$	-42.828 (-2.78)	-14.627 (-1.92)
$\Delta\dot{P}_{t-1}$	-0.371 (-5.01)	--
$\Delta t2_{t-1}$	--	-0.253 (-2.40)
ΔD_t	-2.399 (-2.63)	-1.987 (-3.46)
$\Delta\dot{p}^e_{t-2}$	0.032 (3.03)	0.029 (2.94)
MA(1)	--	-0.705 (6.40)
$\bar{R}^2$	0.30	0.39
S.E.	1.627	1.525
D.W.	2.18	1.94

Table 2
First-Differenced Specifications of the M1-Based P-Star Model

Dependent Variable: $\Delta \dot{P}_t$

Constant	0.537 (2.72)	0.275 (6.12)
$\Delta G1_{t-1}$	-49.229 (-3.35)	-26.973 (-5.69)
$\Delta \dot{P}_{t-1}$	-0.499 (-6.41)	--
$\Delta \dot{P}_{t-2}$	-0.205 (-2.67)	--
$\Delta t2_{t-1}$	-1.021 (-2.70)	-0.579 (-7.27)
ΔD_t	-2.468 (-2.81)	-1.810 (-3.91)
$\Delta \dot{p}^e{}_{t-2}$	--	0.028 (3.09)
$\Delta[\Delta \dot{p}^e{}_{t-1}]$	-0.023 (-3.31)	--
MA(1)	--	-0.882 (17.86)
$\bar{R}^2$	0.39	0.47
S.E.	1.553	1.425
D.W.	2.17	1.83

Figure
A Monetary-Induced Rise in Inflation



In quarter 7, money growth rises 4 percentage points.